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Environmental, technical and financial feasibility study of solar power plants by RETScreen, according to the targeting of energy subsidies in Iran

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ABSTRACT

In this study, based on new electricity tariffs, three scenarios have been developed with The RETScreen International Photovoltaic Project Model, according to the targeting of energy subsidies in Iran. We have also dedicated one of our scenarios to the reduction of greenhouse gasses.

In the first case the electricity price was set to 3.75 Cents/kWh (450 Rial/kWh) and no credit was assigned to the reduction of greenhouse gasses (GHG), therefore equity payback (Return positive cash flow) has been 12.1 year. In the second case the electricity price was set to 17.5 Cents/kWh, therefore equity payback (return positive cash flow) was 8 year. Finally in the last scenario by considering a credit to the reduction of greenhouse gasses and electricity price being 175 Cents/kWh and applying solar panels with high efficiency and suitable batteries (DOD = 60%), equity payback (return positive cash flow) reached within 6 years.

Contents

1. Introduction

In recent years there has been a rising trend toward applying renewable energies all over Iran. The entire electricity consumption in the country has grown by about 10% annually and increased eleven-times over the past 30 years [1]. In 2009, power plant sector used 374.8 Mboe (Million Barrels of Oil Equivalent) including 95.7 Mboe from oil, 273.4 Mboe from natural gas and 1.3 Mboe from coal and 4.4 Mboe from renewable sources to generate electricity equivalent to 130.2 Mboe [1,2].

Currently, renewable energy contributes to only 11% of the world primary energy and this is expected to increase to 60% by 2070 [3]. Even in the Middle East county, as the heart of the fossil resource world, it is estimated that the renewable share in electricity production will reach 16% in the year 2035 from 1% in the year 2008 [3,4].

The biggest environmental issues Iran currently faces are air pollution and carbon emissions. Iran's energy-related carbon emission has been on a steady increase as 452.46% was added over the past 30 years [5].

In 2009 total emissions from the consumption of energy reached an all-time high of 528.603 million metric tons of carbon. With Iran being the world's fourth largest oil-producing country it is not

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surprising that crude oil and petroleum products account for the largest fraction of the Iranian emissions, 46.4% in 2008. Also the ratio of CO_2 (kilograms) to GDP (US dollars) was very high 3.15 in Iran in 2008 as compared to the world average of 0.73. The use of fossil fuels is an important factor in the production of these pollutants in Iran [5,6].

Solar energy is a renewable energy source whose potential is largely unexploited. The average solar radiation for the entire of Iran is about 19.23 MJ/m^2, and it is even higher in the central part of Iran. The distribution of radiation varies between 2.8 kWh/m^2 in the south-east part to 5.4 kWh/m^2 in central region. The calculations show that the amount of practical solar radiation hours in Iran exceeds 2800 h per year [7]. Although Iran's solar potential is excellent, there have been limited applications for solar energy in Iran. One reason has been the price of fuel for producing electricity, and exportation, since 80% of Iran's income is based on oil and gas exportation.

Worldwide there is a tendency, however, to increase the implementation rate of PV systems. Their main advantages are the silent operation and the little maintenance [8,9]. One weakness of PV systems is their high initial costs. Since 1970 the price of PV systems continuously decreased [10]. Also, in the last decade the PV industry has a yearly growth rate of about 30% [11].

However, due to the high import duties on PV modules, inverters, and batteries, the entire installed cost of these systems is still very high in Iran. So solar energy to produce electricity in Iran is not very popular and the price of this source is relatively high at about 10,000 US$/kW. The investment cost of a PV plant depends on its size. It ranges between 4 and 6 US$/W for large plants and exceeds 8 US$/W for smaller plants. This is conservative, taking into account that many PV plants involved are large at present day's standard.

The first photovoltaic (PV) site in Iran, with capacity of 5 kW DC, was established in the central region of Iran in Doorbid village Yazd in 1993. Following this, in 1998, the second photovoltaic site with 27 kW AC capacity was installed in Hosseinian and Moalleman villages in Semnan 450 Km inland from Tehran. The capacity of these power plants has recently increased to 10 kW AC and 92 kW AC respectively. The power plant installed at Doorbid, works independently from the grid system (off grid system), while the one installed at Hosseinian and Moalleman, is connected to grid. It is worth mentioning that all equipment of these sites is made in Iran [7,12]. Tehran Science and Research Branch of IAU solar power plant is the first stand alone-PV power plant that has been installed in university campuses in Iran for teaching and research purposes.

The new targeted subsidies plan in Iran and increasing the purchasing price of produced energy from renewable resources have stimulated the wider use of renewable technologies, such as photovoltaic systems and they are going to be competitive technologies. However, there are some barriers against their diffusion such as, high cost of imported PV modules (due to custom tariffs), low quality of imported PV components (modules and batteries), insecure financing of renewable energy projects, lack of awareness of renewable energy opportunities and still lower prices of fossil fuels in Iran [13].

One of the main difficulties found when trying to compare solar technologies is the lack of consensus about costs. Classic economic evaluations would put PV electricity in the range of 15–50 Cents/kWh, depending on local sunlight and system size. But PV has an unusual, overlooked value: systems can last for a very long time with almost no operating costs. This long life is rarely taken into account. The private sector cannot use it because far-future cash flow does not add to asset value. But we should not be evaluating PV by business metrics [14].

One basic specification should be the levelized electricity cost (LEC) that includes all capital, financing, labor and Operation and Maintenance costs. As the solar photovoltaic (PV) matures, the economic feasibility of PV projects is increasingly being evaluated using the levelized cost of electricity generation, in order to be compared to other electricity generation technologies. It should be noted that the suitable cost comparison is necessary to prevent creating wrong opinion that solar electricity is very expensive. As in one study a new method of loan repayment was developed; so that with graduated payment loan, extension in loan period results in sharp decline in cost of PV electricity in the base year [15,16]. Solar systems are complex and exist in a complex resource and financial environment, so there are many factors which affect life-cycle cost effectiveness [17,18].

Recently, the previous distrust of renewable energies on the part of oil and gas producers countries had changed into a realization that renewable resources are essential components of their national energy supplies, as well as a global strategic option for both extending the life of oil and gas reserves and reducing carbon dioxide emissions and thus combating climate change [19].

Iran's government has also taken some initiatives in this direction, such as targeting the subsidies for fossil fuels, since two years ago, which may lead to an increasing trend toward deployment of renewable technologies.

The increase of energy carrier's prices with the start of targeted subsidies plan in Iran has made the main energy consumers, such as leading consumers and Industries to manage their energy resources in such away to use solar energy for the production of electricity.

The basic average retail price of electricity at the present time is 11 Cents/kWh. Based on the Law of Targeted Subsidies Plan, the new price rates for the electricity consumption are classified in 7 stages:

1. At the first stage: consumption up to 100 kWh will have a rate of 2.2 Cents/kWh.
2. The second stage: consumption of 100–200 kWh will have a rate of 2.6 Cents/kWh.
3. The third stage: consumption of 200–300 kWh will have a rate of 6 Cents/kWh.
4. The fourth stage: consumption of 300–400 kWh will have a rate of 11 Cents/kWh.
5. The fifth stage: consumption of 400–500 kWh will have a rate of 12.5 Cents/kWh.
6. The sixth stage: consumption of 500–600 kWh will have a rate of 15.8 Cents/kWh.
7. The seventh stage: consumption of over 600 kWh will be calculated at 17.5 Cents/kWh.

For the household consumers this rate will be calculated at 3.75 Cents/kWh, and for the consumers living in the tropical climate parts of the country will be at 1.1 Cents/kWh indicated for the household electricity tariff rates. It is necessary to point out that the model consumption rate for the household consumers in Tehran is considered 300 kWh in the summer season and 200 kWh for the other seasons [20].

1.1. *Off-grid PV systems (stand-alone PV systems)*

In this type of system the electrical load requirements are provided by Photovoltaic modules. As a general rule, these systems can be installed and operated as a single power plant with a lifetime of, over 20 years with a high assurance capability. In off-grid system, panels and batteries, independently from the grid can produce Direct Electricity (DC) [21,22]. Generally payback time in a stand-alone PV system is higher than in a grid-connected one. Commercial module efficiencies with monocrystalline modules are between 14 and 20%, and polycrystalline modules are between 12 and 17%. Polycrystalline PV cells are cheaper [23–25].

1.2. RETScreen software

The RETScreen International Photovoltaic Project Model can be used world-wide to easily calculate the energy production, life-cycle costs and greenhouse gas emissions reduction for three basic PV applications: on-grid; off-grid; and water pumping.

The analysis has been performed by using the RETScreen Clean Energy Project Analysis software which is able to perform energy production analysis, financial analysis, and GHG emission analysis. RETScreen software takes into account details such as the energy resource available at project site, equipment performance, initial project costs, "base case" credits, on-going and periodic project costs, avoided cost of energy, financing, taxes on equipment and income (or savings), environmental characteristics of energy displaced, environmental credits and/or subsidies and decision maker's definition of cost-effective [26,27]. One of the primary benefits of using the RETScreen software is that it makes the project evaluation process easier for decision-makers. The financial analysis worksheet, contains financial parameters input items (e.g. discount rate, debt ratio, etc.), and its calculated financial viability output items (e.g. IRR, simple payback, NPV, etc.).

RETScreen simulation software has been used in many studies for assessing the viability of solar photovoltaic as an electricity generation source; as it was used for calculating the technical potential of gird-connected solar PV in Bangladesh. The mean annual electricity generation of the proposed system was 1729 MWh. Also a minimum of 1423 tons of greenhouse gas emissions could be avoided annually utilizing the proposed system at any part of that country [28]. Also the potential for a 10 MW photovoltaic power plant in Abu Dhabi was examined using RETScreen modeling software; which the initial results showed high energy production potential, generating 24 GWh and saving over 10,000 tons of GHG emissions annually [29].

In another study the feasible sites in Egypt to build a 10 MW PV-grid connected power plant was evaluated from techno-economical and environmental points of view by using RETScreen. The financial analysis ensured a good profitability of PV power plant for all the considered sites in Egypt. The environmental impact of such projects was evaluated through GHG emission analysis which showed that the use of PV power plants reduce an average 12,991.1 ton CO_2 emission to the environment. Also the average energy production and capacity factor all over the sites were found to be 26.35 GWh/year and 30.09%, respectively [30].

So, in order to evaluate the financial feasibility of a project RETScreen makes a comparison between a proposed project and a base-case project. The proposed project usually implements a renewable technology, and the base case generally relies on a conventional technology. RETScreen compares the incremental benefits and costs of the proposed project versus the base-case project. There are a number of different steps in a RETScreen analysis of a power project [31–33].

First, the user describes the characteristics of the load and the base case power system.

Second, the user specifies the characteristics of the proposed-case power system, in terms of its performance and incremental capital, operating, and maintenance costs. Third, the user selects the operating strategy for the proposed case power system.

Fourth, a summary section presents for the user to review, the findings of RETScreen's energy model. Fifth, an optional greenhouse gas analysis evaluates the emissions reductions associated with the proposed project versus the base case project, according to a standardized methodology developed in collaboration with the United Nations Environment Program and the World Bank's Prototype Carbon Fund. And sixth, a financial summary determines whether the project is financially feasible, considering cash flows, debt ratios, incentives, and GHG emissions reductions credits.

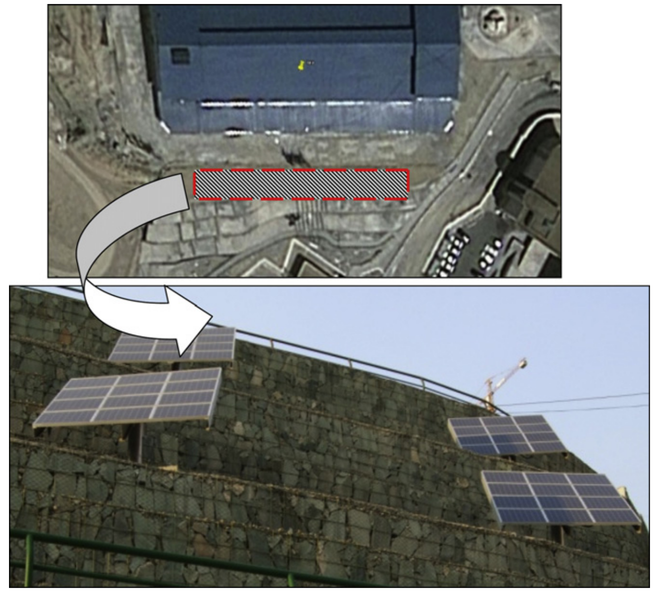


Fig. 1. View of the photovoltaic plant.

The financial analysis can include an optional sensitivity and risk analysis that reveals how changes in inputs affect the viability of the project, in part through a Monte Carlo simulation that reruns the analysis 500 times with random variations in key parameters [32–34].

In order to increase the awareness of the students of renewable energies, Islamic Azad University installed a 12 kW photovoltaic power plant in Science and Technology Branch of IAU. This power plant, is geographically located at, 35.8° North & 51.3° East, and 1660 m from the sea, and is supplying the lighting system for the surrounding area from its own Electricity Production.

Fig. 1 shows the photovoltaic plant.

2. Materials and methods

Details of the installed system configuration are presented as follows.

2.1. PV modules

PV cell technologies can be classified in five classes: the Emerging PV, CdTe, CIS/CIGS, Group III–V, and Silicon. Silicon-based technology is facing market competition from technologies such as CdTe, CIS/CIGS, and Group III–V, etc. selecting the right technology is crucial [35]. Si and GaAs monocrystalline solar cell efficiencies are very close to the theoretically predicted maximum values. The array used in the mentioned 12 KW power plant consisted of 108 mono-crystalline silicon cells, each rated at 120 W, with the 15% efficiency. Each twelve cells mounted on 9 fixed supports structure [36,37].

The energy production analysis shows that compared with the fixed flat plate systems, 1-axis and 2-axis tracking flat plate systems have 22.3% and 25.2% gain in the annual energy production respectively [38]. On the other hand the available maximum power is provided only in a single operating point given by a localized voltage and current known, called maximum power point (MPP). The problem is that the position of this point moves according to the irradiance, the temperature and load. To extract the maximum solar energy permanently, a mechanism is required for the pursuit (tracking) of the maximum power point tracking (MPPT) [39–41].

Unfortunately our under studied PV power plant has a fixed photovoltaic system configuration, so that each module is tilted with an

Table 1
Electrical data of the installed panels for the university PV system.

Nominal power (W_{max})	120 W
Maximum PV array current (operating) (I_{mp})	4.88 A
Maximum PV array voltage (operating) (V_{mp})	24.6 V
Short-circuit current (I_{Sc})	5.143 A
Open-circuit voltage (V_{oc})	30 V

Table 2
Specification of the applied charge controller for the university PV systems.

Voltage	48 V
Nominal short-circuit current (I_{Sc})	140 A
Nominal output current	70 A
Total consumption	14 mA

Angle of 43–50° (south). Other electrical data of the applied panels summarized in Table 1.

2.2. The charge controller and the inverter

The charge controller is used to control the current flow from the array to the battery. The main function of the charge-controller is to protect the battery from over discharge and also from overcharge. With respect to the output voltage of installed panels in the solar power plant, a 48 Volt Charge Controller with Model No 48-160 from STECA Company has been used (Table 2).

Inverter is an electronic device which converts the DC electricity to AC electricity which most appliances run on it. It is necessary to point out that the mentioned inverters which are used in stand-alone systems are very much different from those used in on-grid systems, because they must have the capability to ensure all the AC appliances requirements and also to have a sufficient efficiency. The inverters of PV systems usually come in two models, ON-GRID & OFF-GRID, which have a 70–96% efficiency (Table 3). The inverters which have been used in the university are made by the STECA Company, have an 8 KW rated power [14,42,43].

2.3. The batteries

The type of batteries which are used in stand-alone solar systems is generally the lead-acid. Nominal voltage of a lead-acid cell is 2 VDC.

Long lasting quality, low water loss, isolated system structure without any leakage of electrolyte from the terminals of the battery, and a long life time with minimum possibilities of self discharging, are the major benefits of these batteries which can be mentioned. The energy storage capacity of batteries can be expressed in kilowatt-hours (kWh) which is equal to the rated capacity in ampere-hours by the nominal battery voltage (in volt), and dividing it by 1000. So by using 24 nominal 2 V and 2000 A h batteries, the total storage capacity of the power plant would reach up to 96 kWh. As mentioned, the battery bank of the university PV power plant consists of 24 lead-acid cells of 2 V each. The cells are connected in series to provide 48 V nominal storage voltages (Table 4). The total capacity of the battery bank is 2000 A h [13,44,45].

In this research, for evaluation of the return of investment for understudied PV power plant, 3 main scenarios have been taken into consideration. According to the calculations which have been done, and with the help of a software called RETScreen, it is observed that in the third scenario, by choosing the proper batteries, long lasting panels with better qualities, and assigning the credit for GHG emissions reduction. The return time of the investment can be reduced significantly (up to 50%) [16,17].

Table 3
Specification of the applied inverter for the university PV systems.

Nominal power	8000 W
Input voltage	48 V
Output voltage	230 V (pure sinus)
Nominal continuous output power	7000 W
Efficiency	96%

Table 4
Electrical data of the applied batteries for the university PV systems.

Nominal voltage	2 V
Capacity	2000 Ah
Maximum rate of charge	400 A
Maximum rate of discharge	11,000 A (5 s)

3. Results and discussion

In the review of effectiveness of the targeted subsidies law, in regard to being economically cost effective for the construction of photovoltaic power plants, a project financial analysis in the form of 3 scenarios were prepared, which included making a comparison of the cost of covering the total electrical estimated load by a photovoltaic power plant, with providing it by the central grid. In all 3 scenarios inflation rates were equal to 10.8%, based on the goods and consumer services cost indicator in Iran's different city areas in the year 2010. Some of other financial figures for the analysis were fuel cost escalation rate 14.9%, discount rate of 20%.

In the first scenario, the lowest price for electricity consumption and in the second & third scenario, prices for the consumers using electricity over the designated kWh were considered.

In addition to this, the effects of improving the quality of the applied batteries by characteristic change of maximum allowable depth of discharge were analyzed.

In the last scenario, the desired conditions of the construction of photovoltaic power plant were reviewed. This scenario was considered with assumption of the credit 30$ assigned per equivalent ton of CO_2, in order to quantify the benefits of GHG emission reduction (prices varied between 1 US$ and 100 US$/ton of CO_2; further more in some of the Asian countries an average damage cost 20$/ton CO_2 has been set) [46]. Iran's renewable energy organization has taken some actions to approve this credit discount. Also a financial grant equal to 20% of the total initial cost of investment was considered In the third scenario, which shows the government's encouraging policies effective actions for making such renewable projects possible (Table 5) (this figure can also be improved dependent on the government's policies) [43–45].

Table 5
Given common data for all the 3 scenarios of the understudied 12 kW PV power plant.

Elevation	1660 m
Daily solar radiation – horizontal	4.92 kWh/m^2 day
Daily solar radiation – tilted	5.13 kWh/m^2 day
Annual Electricity – AC	60 kWh
Inverter capacity	8 kW
Battery voltage	48 V
Type of PV panels	Mono-crystalline
Electricity delivered to load	13.01 MWh/year
Total initial cost	110,000$
Annual costs/(O&M)	1700$
Annual GHG reduction	12.3 ton CO_2
GHG reduction – 20 years	247 ton CO_2
Discount rate	20%
Inflation rate	10.8%
Fuel cost escalation rate	14.9%
Project life	20 years
Debt ratio	0
Capacity fact	14.3%

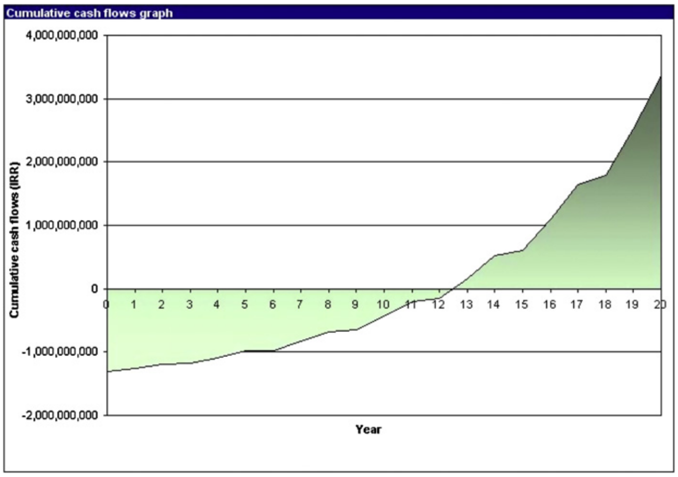


Fig. 2. Cash flows over the project life of the first scenario.

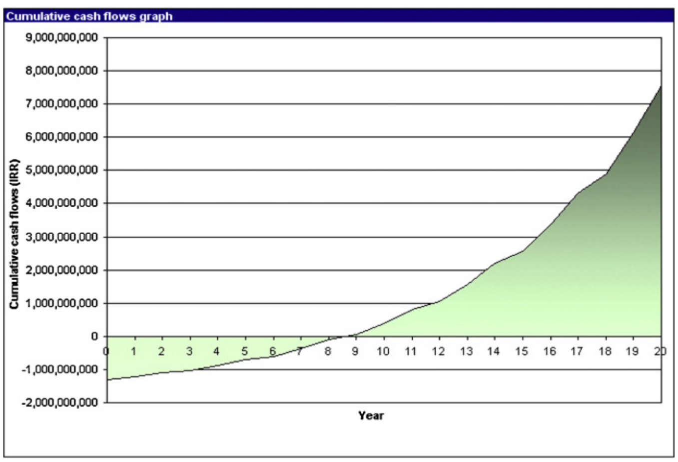


Fig. 3. Cash flows over the project life of the second scenario.

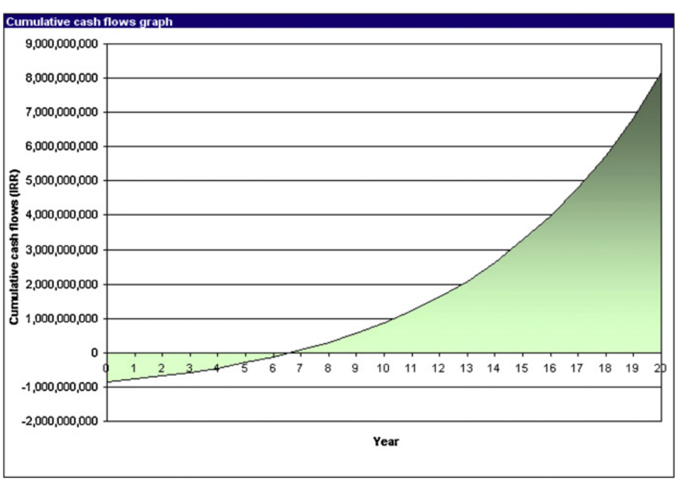


Fig. 4. Cash flows over the project life of the third scenario.

4. Conclusion

In the first scenario the average price for the central grid electricity of 3.75 Cents/kWh was assumed, and any credit for the reduction of Greenhouse emissions was not considered. Must also mention that at this state, PV systems real technical conditions were considered in the calculations and the amount of 60 kWh daily loads was considered for the project.

Based on the achieved results, the internal rate of return equals to 10.2% and the simple payback time equals to 40.7 years, and the equity payback time equals to 12.1 years (Fig. 2).

In the second scenario with respect to the 1800 kWh electricity consumption per month, the maximum price per kWh of electricity (17.5 Cents/kWh) based on the targeted subsidies law, has been considered into the calculations and no credits has been considered for the reduction of greenhouse gasses. It must be mentioned that at this state, the power plant's real technical conditions were considered in the calculations and the amount of 60 kWh daily loads was taken into consideration. Based on the achieved results, the internal rate of return equals to 18% and the simple back time equals to 16.9 years, and the equity payback time equals to 8 years. Therefore as it can be observed, the increase of prices of energy carriers has had a quite positive effect in reducing the return period of the investment, in a way that if the retail price of electricity were quadrupled with respect to the first scenario the return period of the investment would be reduced by 3 times (Fig. 3).

In the third scenario, the average price of 17.5 Cents/kWh electricity was assumed for the grid electricity and a credit equivalent to $30 for the reduction of one ton of greenhouse gasses was taken into consideration. Also the type of batteries used in the system, was from a special type with a high depth of discharge (60% battery capacity), and the daily load of 60 kWh was the base which was taken into consideration for the power plant.

Based on the achieved results, the internal rate of return has been equal to 21.9%, and the simple payback time equals to 12.3 years, and equity payback time equals to 6 years (Fig. 4).

Based on the calculations in the third scenario, taking into consideration the reduction of greenhouse emissions and the price of electricity at 17.5 Cents/kWh, and by using high quality PV panels and proper batteries (about 60 DOD%), the period for receiving the positive cash flow would reach 6 years. Based on this, the increase of purchasing price for the produced solar electricity and using the latest innovative technologies, especially in batteries and panels and adopting supportive policies from the government, can reasonably reduce the investment return period. Also to increase solar energy extraction, tracking systems especially the ones equipped with a maximum power point (MPP) tracker is suggested.

It is necessary to point out that, in addition to the technical issues, the Greenhouse gasses reduction credits has been effective in reaching the 6 years of payback time. And with respect to the 20 years lifetime of the power plant, the initial necessary credits should be obtained and this fact will have a key role in reducing the return of the initial investment period. There is a need to expand international collaboration in PV research, development, capacity building and financing to accelerate learning and avoid duplicating efforts. Governments and industry must increase R&D efforts to reduce costs and ensure PV readiness for rapid deployment, while also supporting longer-term technology innovations. There are other policy instruments that can indirectly support deployment of renewable energy resources in the long term. These indirect strategies can be in the form of environmental taxes, or of emission permits for electricity produced by non-renewable sources, as well as the removal of subsidies given to fossil fuel and nuclear generation. Additionally, they could be in the form of simplification and standardization of renewable-based generation connection procedures. Finally, the establishment of regulations that govern intermittency-related balancing costs can indirectly support deployment of renewable sources [47].

Financial support and promotion schemes are usually required; also private financing is envisaged [48]. For more than three decades the feed-in tariff schemes are used in Europe as the main price-based policy instrument to support PV systems

implementation [49]. Different quantity-based support mechanisms are also used in various countries, such as direct investment subsidies, tax rebates and incentives as well as renewable portfolio standards and tradable green certificates [50–52]. Results show that regional government policy clearly helps promote PV system adoption. Also housing investment and environmental awareness among residents have positive effects on PV system adoption. PV systems not only create employment and promote economic revitalization but also contribute broadly to economic development by bringing electricity to parts of the world not yet covered by a power grid.

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